

## **“Hurricanes Daily” Langley’s Full Scale Wind Tunnel and the Sublime**

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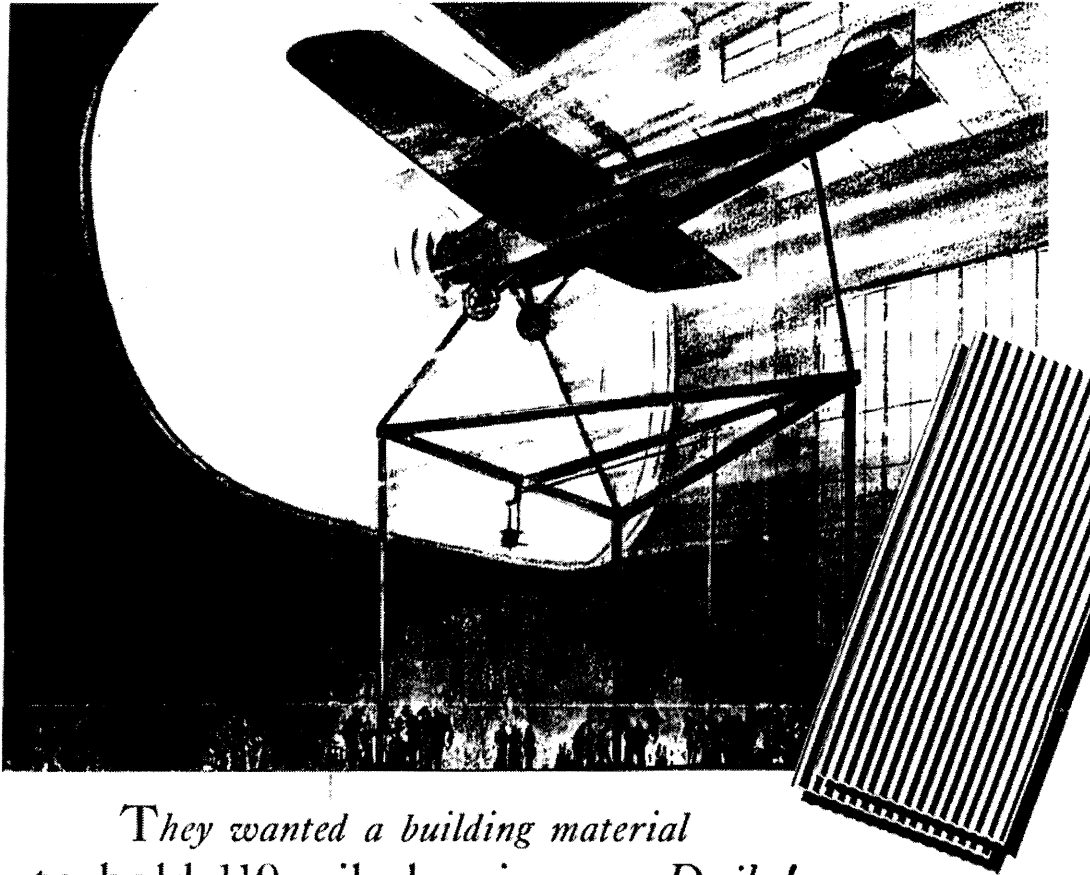
In June 1930, a striking full-page advertisement in the *Saturday Evening Post* touted the features of Careystone Corrugated Asbestos Roofing and Siding material. “They wanted a building material to hold 110-mile hurricanes • *Daily!*” screamed the bold type-face lead. Readers of the *Post* did not normally view the popular magazines as a source of information about highly specialized building materials for industrial applications. Yet, the Philip Carey Company of Cincinnati, Ohio placed the ad to describe the construction of a remarkable new wind tunnel at the National Advisory Committee for Aeronautics’ laboratory in Hampton, Virginia. The NACA already had the world’s largest wind tunnel (the Propeller Research Tunnel) and now it was building an even bigger facility—one large enough to test full-sized airplanes.<sup>1</sup> The advertisement offered a foretaste of the kind of hyperbole and emotional rhetoric that would become commonplace for descriptions of the NACA’s Full Scale Tunnel.

Almost a year after the *Post* ad, on May 27, 1931, the NACA “dedicated” the wind tunnel during its Sixth Annual Aircraft Inspection. Although George Lewis, the NACA’s Director of Research planned modest ceremonial “start-up” of operations neither the press nor the visiting engineers could contain themselves.<sup>2</sup> Article after article gushed

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<sup>1</sup> “They wanted a building material to hold 110-mile hurricanes • *Daily!*,” Advertisement by the Philip Carey Company, copyrighted by the P.C. Mfg. Co., 1930, in the *Saturday Evening Post*, June 7, 1930.

<sup>2</sup>G.W. Lewis to Langley Memorial Aeronautical Laboratory,” May 12, 1931. (National Archives and Records Administration--Mid-Atlantic Branch, hereinafter NARA-Phila) NARA-Phila, RG 255, Box 1021.



## They wanted a building material to hold 110-mile hurricanes · Daily!

Whirr-r-r! An airplane swoops hawklike out of the sky . . . motor roaring . . . struts singing . . . and nose down. But, a few feet off the ground, it pulls up, and levels off sweetly. Hazardous, you think, as you catch your breath. How could the pilot be sure his craft would meet the emergency, withstand such strain?

To determine how aircraft will behave—beforehand—is one of the functions of the National Advisory Committee on Aeronautics, official government research organization for aeronautics. To get these facts—scientifically

the Committee maintains laboratories at Langley Field, Va. laboratories, by the way, whose services are available to the entire aircraft industry.

In one of these laboratories is the largest wind tunnel in the world—and to this, a second even larger tunnel is now being added. One large enough to test full-sized airplanes and airplane parts in a wind-stream of 110-mile velocity! In this air-stream pulled through the tunnel by fans of 8,000 horsepower—the airplane, or part under test, will be subjected to conditions closely approximating those of actual flying.

In the building to contain this tunnel were unusual conditions to meet. What sort of siding material would withstand the daily gusty buffeting of these 110-mile hurricanes? The choice was Careystone Corrugated Asbestos Roofing and Siding because it combines many desired qualities. Made of cement and

tough asbestos fibres, merged into stone-hard sheets of extraordinary resiliency and strength, it is a superior siding for factories, powerhouses, chemical plants, garages, shops and every kind of industrial building. Then, too, it is resistant to acid and alkali, fire and frost—and actually gains strength with age. A good material to keep in mind when next you have a job of your own to plan for!

THE PHILIP CAREY COMPANY  
Cleveland, CINCINNATI, OHIO  
Offices in the Principal Cities

Philip  
**Carey**  
Products

### Carey Asbestos Magnesia Asphalt Products

*For Industry:* bonded Asbestos Built-up Roofs; Asbestos Water-proofing for Foundation Walls; Elastite Industrial Flooring; Asbestos and Magnesia Heat Insulations and Pipe Covering for Power Plants, and many other Asbestos, Magnesia and Asphalt specialties; Asbestos Pipe Line Pelt for the Oil Industry.

*For Homes:* Asphalt Flexible Siding; Bonded Asbestos Shingles; Roof Roofing; Asbestos Hot Water Tank Jackets; Elastite Expansion Joint for Sidewalks and Curbs; Runways.

*For Transportation:* Elastite Expansion Joint for Concrete Highways; Elastite Bridge Flooring; Elastite Railroad Crossing; Elastite Rail Filler for Street Railways; Asbestos and Magnesia Blocks and Coverings for Railroad and Steamship Liners; Asbestos Brake Lining for Automobiles.

enthusiastically. Alexander Klemin, writing for *Mechanical Engineering*, stated: “The impression created on visitors to the new tunnel is one of awe--the awe inspired by a cathedral.”<sup>3</sup>

Although the Full Scale Tunnel did emerge as an important facility, there was hardly a unanimous consensus that this represented the best investment of the NACA’s financial resources. The value of full-scale testing of aircraft was questioned by aerodynamicists during the 1920s and 30s and even at Langley, the engineers were of divided opinion. Yet, even before operations had yielded up much research data, the Full Scale Tunnel was considered one the NACA’s most important wind tunnels, on par with the Variable Density Tunnel and the Propeller Research Tunnel.

This paper explores the powerful emotional reactions that the FST evoked among a nascent aeronautical engineering community. The FST proved to be the critical mechanism for bridging the gap between those engineers who identified themselves as “theoretical men” and those who were more interested in empirical research or practical hands-on design problems. The theme of the “sublime” is inspired by David Nye’s work on the technological sublime but I have focused on how “emotion”-- specifically the sublime expressions of wonder and awe--defines and motivates a *single* technical community (as opposed to the larger society).<sup>4</sup> It forms part of a larger study of federal contributions to the establishment of aeronautical engineering as a unique discipline. The perception (as much as the reality) that the NACA provided its engineers with bold and imaginative technical tools (such as the Full Scale Tunnel) to undertake its research would prove critical to the establishment of the Langley lab as vital center and the NACA as one of the world’s preeminent agencies for aeronautical research.

### *Scaling Up*

Historian Alex Roland noted that the wind tunnel is the symbolic instrument of the

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<sup>3</sup>Alexander Klemin, “Recent Aircraft Engineering Research,” *Mechanical Engineering* 53 (August 1931): 598.

<sup>4</sup>David E. Nye, *American Technological Sublime*, (Cambridge: The MIT Press, 1994).

aeronautical engineering profession.<sup>5</sup> When, just after the turn of the century, academic scientists and engineers accepted the "flying machine" and aerodynamics as a legitimate subject of inquiry, wind tunnel construction likewise flourished.<sup>6</sup> Unlike the modest wooden box built by the Wright brothers in 1901, most of the wind tunnels and whirling arms built in the years before 1918 were large and fairly expensive undertakings. The tunnel built by Albert Zahm at Catholic University completed the same year as the Wright brothers' tunnel, took five years to build and was fifty feet long, had a six-foot test section and a ten horsepower fan which air speeds up to 25 miles per hour.<sup>7</sup> In 1918 J.R. Pannell informed the Royal Aeronautical Society of Great Britain that the two newest tunnels built by the National Physical Laboratory cost more than \$13,000<sup>8</sup> and the NACA spent \$38,000 to build its first Atmospheric Wind Tunnel. While hardly exorbitant, these were not sums expended by too many "gentlemen of science" either.<sup>9</sup>

The interest in tunnels was a consequence of a major evolution in the field of aerodynamics --the development of Boundary-Layer Theory. In 1900, a 26-year old Ph.D. graduate from the University of Munich was hired as an engineer for a Nürnberg branch of a large German machine manufacturer. Though his specialty was in solid mechanics, Ludwig Prandtl was assigned a fluid mechanics problem—to build a better suction device to collect shavings produced by lathes. Within a year Prandtl had come up with a new design and a new intellectual interest. For the next three years, Prandtl continued to study and

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<sup>5</sup>Alex Roland, *Model Research: The National Advisory Committee for Aeronautics, 1915-1958*, Vol. 1, (Washington: NASA SP-4103, 1985), p. xiv.

<sup>6</sup>John D. Anderson, Jr., *A History of Aerodynamics and Its Impact on Flying Machines*, Cambridge Aerospace Series, (New York: Cambridge University Press, 1997), p. 260.

<sup>7</sup>H. Mattullath and A.F. Zahm, "New Methods of Experimentation in Aerodynamics," Paper given at the meeting of the American Association for Advancement of Science, Pittsburg (sic), June, 30, 1902, reprinted in *Aeronautical Papers 1885-1945 of Albert F. Zahm, Ph.D.*, Vol. 1, (Notre Dame, Ind.: The University of Notre Dame, 1950), pp. 105-111; Tom D. Crouch, *A Dream of Wings: Americans and the Airplane, 1875-1905*, (New York: W.W. Norton, 1981), p. 131.

<sup>8</sup>J.R. Pannell, "Design and Use of Wind Tunnels," *Journal of the Society of Automotive Engineers*, 11 (March 1918): 245.

<sup>9</sup>James R. Hansen, *Engineer In Charge: A History of the Langley Aeronautical Laboratory, 1917-1958*, (Washington: NASA SP-4305, 1987), p. 442.

experiment with new ways of understanding fluid mechanics while teaching at a Technische Hochschule in Hannover. At the Third International Congress of Mathematicians held in Heidelberg in 1904, he gave a short ten page paper on a phenomena called the Boundary-Layer. Prandtl's paper swiftly proved to be of fundamental, revolutionary, importance to a nascent field of aerodynamics.<sup>10</sup>

"Normal Science," wrote Thomas Kuhn in his famous book, *The Structure of Scientific Revolutions*, "means research firmly based upon one or more past scientific achievements, achievements that some particular scientific community acknowledges for a time as supplying the foundation for its further practice."<sup>11</sup> When anomalies are discovered, the subsequent creation of new scientific theories can precipitate a revolution. Numerous groups offer competitive explanations to replace the "old" and "discredited" theory. The establishment of a new paradigm (which encompasses law, theory, application and instrumentation) requires practitioners to accept that one theory is better than its competitors.<sup>12</sup> In the heady excitement of successful experimentation with heavier-than-air machines, scientists interested in flight had been struggling for a way to explain aerodynamic drag. Prandtl articulated the new paradigm for theoretical aerodynamics.

In less prosaic terms, Prandtl's theory supplied a research agenda and a rationale for building "wind tunnels."<sup>13</sup> Prandtl himself, just a few months after delivering his papers, was snapped up by Germany's most prestigious research university--Göttingen--where he immediately developed a closed-circuit tunnel (prior to this time, wind tunnels were open tubes) and began developing a research center which would produce some of the most

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<sup>10</sup> Anderson, pp. 251-253, 257-258; L. Prandtl, "Über Flüssigkeitsbewegung bei sehr kleiner Reibung," in *Verhandlungen des Dritten Internationalen Mathematiker-Kongresses in Heidelberg vom 8. bis 13. August 1904* (Leipzig: Internationalen Mathematiker-Kongress, 1905; reprint, Nendeln and Liechtenstein: Kraus Reprint Limited, 1967), pp. 484-491.

<sup>11</sup> Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 2nd ed., (Chicago: University of Chicago Press, 1970), p. 10.

<sup>12</sup> Kuhn, pp. 10, 17.

<sup>13</sup> The term "wind tunnel" introduced by Gustav Eiffel in 1910 although it did not come into English use until 1913 when Jerome Hunsaker translated the paper for the NACA. Anderson, p. 275.

significant figures in aerodynamics history--Max Munk, Theodore von Kármán, Adolf Busemann, and Jakob Ackeret.<sup>14</sup> During the next 15 years, several university or government organizations constructed substantial wind tunnel facilities (the exception was Gustav Eiffel's personal laboratories at Champ de Mars and Auteuil) in Europe, Russia, Japan and the United States. As experimentation with this new instruments got underway, researchers at all of these sites realized they had to grapple with a seemingly intractable problem of wind tunnel testing--scale effects.

Experimental results produced by small-scale models in the wind-tunnels did not correlate with the results obtained through flight testing. By 1920 this discrepancy based on model size had been identified. Researchers had discovered that model size, air density and viscosity could be combined into a single mathematical coefficient that helped them understand their results. This coefficient had been at the heart of an important debate between Ludwig Prandtl and Gustav Eiffel and in the course of this "exchange" it became known as the Reynolds number.<sup>15</sup>

In 1921, Max Munk, one of Prandtl's star pupils recruited by the National Advisory Committee for Aeronautics (NACA) proposed a radically new type of wind tunnel which he believed would produce results similar to full-scale flight. Munk recognized that increasing the density of the air, that the Reynolds numbers for small scale model tests would be similar to full-scale flight tests. His plan was to put a wind tunnel inside a pressure vessel. As water or other liquids were too dense, Munk's idea was to compress air.<sup>16</sup>

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<sup>14</sup>Anderson, pp. 258-260.

<sup>15</sup> In 1883 Osborne Reynolds published "An Experimental Investigation of the Circumstances which Determine whether the Motion of Water in Parallel Channels Shall be Direct or Sinuous, and of the Law of Resistance in Parallel Channels" in the *Philosophical Transactions of the Royal Society* (Series A, Vol. 174, 1883, pp. 935-82.) In experiments studying the flow of fluids in pipes, Reynolds observed that the relationship between density and viscosity affected the flow patterns of the fluid in the pipe. In particular, he found that these factors--in combination--identified the precise moment fluid flow changed from sinuous (today, we use the term "laminar") to turbulent. Prandtl and Eiffel's "debate" concerned measurements of drag on spheres. Various experiments were conducted in Germany and France during the teens.

<sup>16</sup> Max Munk, "On a New Type of Wind Tunnel," NACA Technical Note, No. 60, May 1922.

It was a brilliant proposition and the Variable Density Tunnel (VDT) which began operations in 1922 brought international recognition to the NACA's new laboratory in Hampton, Virginia. When in operation the tunnel was pressurized to 20 atm which meant that 1/20 scale models (the size used in the tunnel) were supposed to produce full-scale Reynolds numbers. The results were indeed startling to engineers and scientists but the test results were not perfect. Eastman Jacobs reported in *Aviation* that in the first four years of operation several airplane designers had made use of VDT data but he wrote, "it is very difficult to devise an experiment which gives direct comparison between the results of tests in the tunnel and the results of full scale tests in free air."<sup>17</sup> Even without such tests, many were beginning to sense that turbulence was the main culprit but the inability to correct the problem easily gave advocates for a different sort of wind tunnel an opening for discussion. Instead of manipulating Reynolds numbers, why not build a tunnel large enough to test full-size airplanes or components? This idea gained currency in the 1920s but was generally dismissed as unrealistic and expensive. Still, it had strong intuitive appeal—especially for experimentalists and tinkerers.<sup>18</sup>

#### *A New Kind of Research Tunnel*

The idea for Langley's Full-Scale Wind Tunnel originated with George W. Lewis, the peripatetic and avuncular, engineer-entrepreneur, who had been named Director of Research for the NACA in 1919. Lewis "kept up" with new technical developments in aviation better than anyone in the United States. He noticed people, engaged them in dialogues, asking question after question about their work, and whether the NACA had done or *could do* anything for them. In February 1924, a young engineer named Fred Weick reported to work as the "first civilian assistant for propellers" at the Navy's Bureau of Aeronautics. Weick soon discovered the technical library of the NACA located in an

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<sup>17</sup> Eastman N. Jacobs, "Work in the Variable Density Wind Tunnel of the N.A.C.A.," *Aviation* 23 (September 12, 1927): 621.

<sup>18</sup>Hansen, see Chapter 3, "The Variable-Density Wind Tunnel," pp. 65-95.

adjacent wing of the Navy Building and George Lewis soon discovered Fred Weick.<sup>19</sup>

In 1924, most of the NACA's propeller work had actually been conducted by Stanford University engineers William F. Durand and Everett P. Lesley. Weick, like most others interested in propellers, relied on the Stanford studies for both content and method.<sup>20</sup> In 1924 though, Weick became very interested in British propeller experiments with high-tip-speed. When Lewis asked Weick one day about how the NACA could help the Bureau of Aeronautics, Weick responded that he thought full-scale propeller tests at high tip speed would represent a very valuable research program. At the time however, Weick thought flight tests would be the only way to do this work. No wind tunnel existed which could run this sort of test.<sup>21</sup>

George Lewis proposed this problem to Max Munk. Munk knew that Theodore von Kármán had built a wind tunnel for propeller experiments as part of the Austro-Hungarian Aviation Corps' Military Aircraft Factory near Fischamend, Austria. While Munk was not familiar with the details of von Karman's work, he knew enough to make this the basis for his recommendation for a separate facility for propeller work. In the middle of a memorandum to Lewis on this subject he mentioned in passing that "the laboratory would be available as largest wind tunnel in the world." To test a 10-foot propeller would require a tunnel with a 20-foot test section. Munk proceeded to sketch out such a facility and noted that despite the large size he thought the cost would not be "excessive."<sup>22</sup>

Lewis immediately set up a conference with Leigh Griffith, Langley's Engineer-in-Charge. Griffith invited several Langley engineers to participate in the discussion. On

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<sup>19</sup> Fred E. Weick and James R. Hansen, *From the Ground Up: The Autobiography of an Aeronautical Engineer*, (Washington: Smithsonian Institution Press, 1988), pp. 35-39.

<sup>20</sup> See Chapter 5, "Data for Design: The Air-Propeller Tests of W.F. Durand and E.P. Lesley, 1916-1926," in Walter G. Vincenti, *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History*, (Baltimore: The Johns Hopkins University Press, 1990).

<sup>21</sup>Weick and Hansen, p. 46.

<sup>22</sup>"Laboratory for Testing Full Size Propellers," memorandum from Max Munk to Mr. Lewis, March 10, 1925, NARA-Phila, RG 255, Box 1013.



Friday, April 3, 1925, Elliott G. Reid, a young assistant engineer who had worked at Langley since his graduation from the University of Michigan in 1922, submitted to Griffith a seven-page memorandum enthusiastically endorsing the idea of for the “Proposed Giant Wind Tunnel.” At the very end, Reid appended this thought:

The suggested 20 ft. throat diameter seems ample except for one possibility which was not mentioned in the list above. It would be a marvelous asset to be able to test scaled-down models of large airplanes and having the models capable of actual flight. This could be done in many cases if the tunnel were to have a throat of about 30 ft. diameter, but any model capable of carrying a pilot would be too large for a 20 ft. tunnel. The comparison of flight and tunnel tests on the same model would be just about the ne plus ultra of aerodynamic investigation.<sup>23</sup>

The idea electrified Griffith who spent the weekend studying the report. Monday he drafted a response and Tuesday morning, April 7, sent Elliott Reid’s full report along with a memo highlighting the proposal for an even larger wind tunnel to George Lewis. Lewis passed a copy of the Griffith’s note with Reid’s memorandum on to Max Munk for comment but his reply to Griffith already suggested that the likely response to the proposal for a 30 foot tunnel would be negative. Lewis did not respond to Reid’s passionate expression of an aerodynamicist’s dream facility, rather he simply stated that he felt it would be impossible to carve out enough land on the Committee’s small plot at Langley Field to accommodate a larger building. Lewis’ memo arrived Friday the 10th but Griffith waited until Monday to show Elliott Reid the disappointing news.<sup>24</sup>

Griffith pitched the idea one more time. He asked Arthur Gardiner, one of Lewis’ former students who now worked as an engineer at Langley, to review Elliott Reid’s

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<sup>23</sup>“Memorandum on Proposed Giant Wind Tunnel” from Elliott G. Reid to Leigh Griffith, April 3, 1925, NARA-Phila, RG 255, Box 1013.

<sup>24</sup>“Discussion of proposed giant wind tunnel,” memorandum from Leigh M. Griffith to National Advisory Committee for Aeronautics (Director of Research), April 7, 1925; “Discussion of proposed propeller test tunnel,” memorandum from National Advisory Committee for Aeronautics (G.W. Lewis) to Langley Memorial Aeronautical Laboratory, April 9, 1925, NARA-Phila, RG 255, Box 1013

proposal. Predictably, Gardiner's report endorsed the idea for a 30 foot tunnel.<sup>25</sup> Griffith sent a second memorandum to George Lewis, enclosing Gardiner's report. This time his appeal to Lewis was bolder.<sup>26</sup> It was also too late. Lewis had already obtained Congressional approval for a propeller test tunnel. Lewis, Munk, and now Fred Weick (who Lewis had recruited from the Navy to run the new tunnel) as well as the Navy, were committed to building the smaller Propeller Research Tunnel (PRT).<sup>27</sup>

In 1927 Elliott Reid left Langley on a sour note to become a professor at Stanford University. Rejections such as the one he experienced with his idea for a Full-Scale wind tunnel had been painful and maddening. Reid disliked Lewis although he conceded that Lewis respected him. Bright and imaginative, he was supremely confident in his research abilities.

The idea of being free to do some of the things I have wanted to do without having to stop to demonstrate to the Army or Navy that some designer or inventor or plain fool has figured that  $2 \times 2 = 6$  is a great attraction. I think that I know some lines of really new research that would make some of the "old heads" scratch hairs from their beards (yes, Prandtl, et al)....<sup>28</sup>

Max Munk had been fired (technically, he resigned) earlier that year, and Reid felt that he could have been promoted to the head of the Aerodynamics Division (he was then head of the Atmospheric Wind Tunnel section) had he wanted to stay at Langley. He was eager to leave and pursue a new direction in work on boundary layer theory.<sup>29</sup>

The idea for a full-scale wind tunnel--bigger than the PRT--did not leave with Reid,

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<sup>25</sup>"Memorandum on Proposed Giant Wind Tunnel," from Arthur W. Gardiner to Leigh Griffith, April 22, 1925, NARA-Phila, RG 255, Box 1013

<sup>26</sup>"Memorandum on proposed giant wind tunnel - A.W. Gardiner," from Leigh M. Griffith to National Advisory Committee for Aeronautics (G.W. Lewis), April 22, 1925, NARA-Phila, RG 255, Box 1013

<sup>27</sup>The Propeller Research Tunnel was completed in 1927.

<sup>28</sup>Letter, Elliott Reid to E.P. Lesley, April 18, 1927, Stanford University, SC 230, Box 9, Folder 27.

<sup>29</sup>Reid never had quite the influence of Prandtl but generations of Stanford students including Walter Vincenti, speak of him with great respect, especially about his exacting standards for wind tunnel work.

however. In August 1927, fire broke out in the Variable Density Tunnel and destroyed the interior. That set the stage for an intense period of redesign. Engineers hoped that in the redesign the intense airstream turbulence could be eliminated. The fire also reopened the whole full-scale debate again. Discussions of a full-scale wind tunnel could proceed now that Munk was gone and the facility that the Navy wanted was complete. In early 1928, NACA chairman, Joseph Ames wrote to the Director of the Budget proposing the idea of a full-scale tunnel.<sup>30</sup>

By June 1928, Henry Reid was submitting drawings and cost estimates for a full-scale wind tunnel.<sup>31</sup> On July 1, 1928 (the start of the new federal fiscal year), the NACA got its first \$5,000 for preliminary design work. The A team of engineers led by Smith DeFrance and Elton Miller team had already determined that the tunnel would cost about \$527,000. As electric power supply in Hampton remained grossly inadequate, the engineers had proposed four different powerplant options which added between \$169,000 and \$352,000 to the total costs. Persuading Congress to allocate funds was expected to be a big challenge. The tunnel was not going to be cheap, especially when compared with the PRT which had cost \$291,000 to construct..<sup>32</sup>

External events made the winning political support much easier. President Coolidge and his dynamic Secretary of Commerce, Herbert Hoover, already supported the principle of sustained federal support of aviation. The key event was the publication in November 1928 of Technical Note 301 that reported Fred Weick's astonishing cowling research results. Technical Notes did not usually garner much interest from the general American public but they were read eagerly by engineers around the world. Weick and his team had discovered an engine cowling design that reduced drag by a factor of 3. Flight tests that

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<sup>30</sup>Joseph S. Ames, "Dedication of Full-Scale Wind Tunnel," in U.S., National Advisory Committee for Aeronautics, "Report of Proceedings of Sixth Annual Aircraft Engineering Research Conference," May 27, 1931, pp. 22-23.

<sup>31</sup>"Drawing to accompany estimates on full scale wind tunnel," memorandum from H.J. E. Reid to National Advisory Committee for Aeronautics, June 28, 1928, NARA-Phila, RG 255, Box 1021.

<sup>32</sup>Keller, pp.135-136; Hansen, p. 444.

fall and winter confirmed the results, and a spectacular transcontinental record flight on February 4-5, 1929 brought the NACA tremendous acclaim—both nationally and internationally.

### *Construction*

George Lewis capitalized on that enthusiasm and interest during Congress' annual appropriations votes that same month. It is likely that Lewis first began advancing the argument that the annual savings to industry through the use of the NACA cowling would be at least \$5 million. That sum was more than the combined total all NACA appropriations between 1915 and 1928. Still, in the end, the tunnel did not require much of a hard sell to Congress. On February 20, 1929 the NACA received a two-year, \$900,000 appropriation from Congress. A month later on March 27, Elton Miller announced in a general memorandum that a Full Scale Wind Tunnel section had been formed with Smith DeFrance as the new section head.<sup>33</sup>

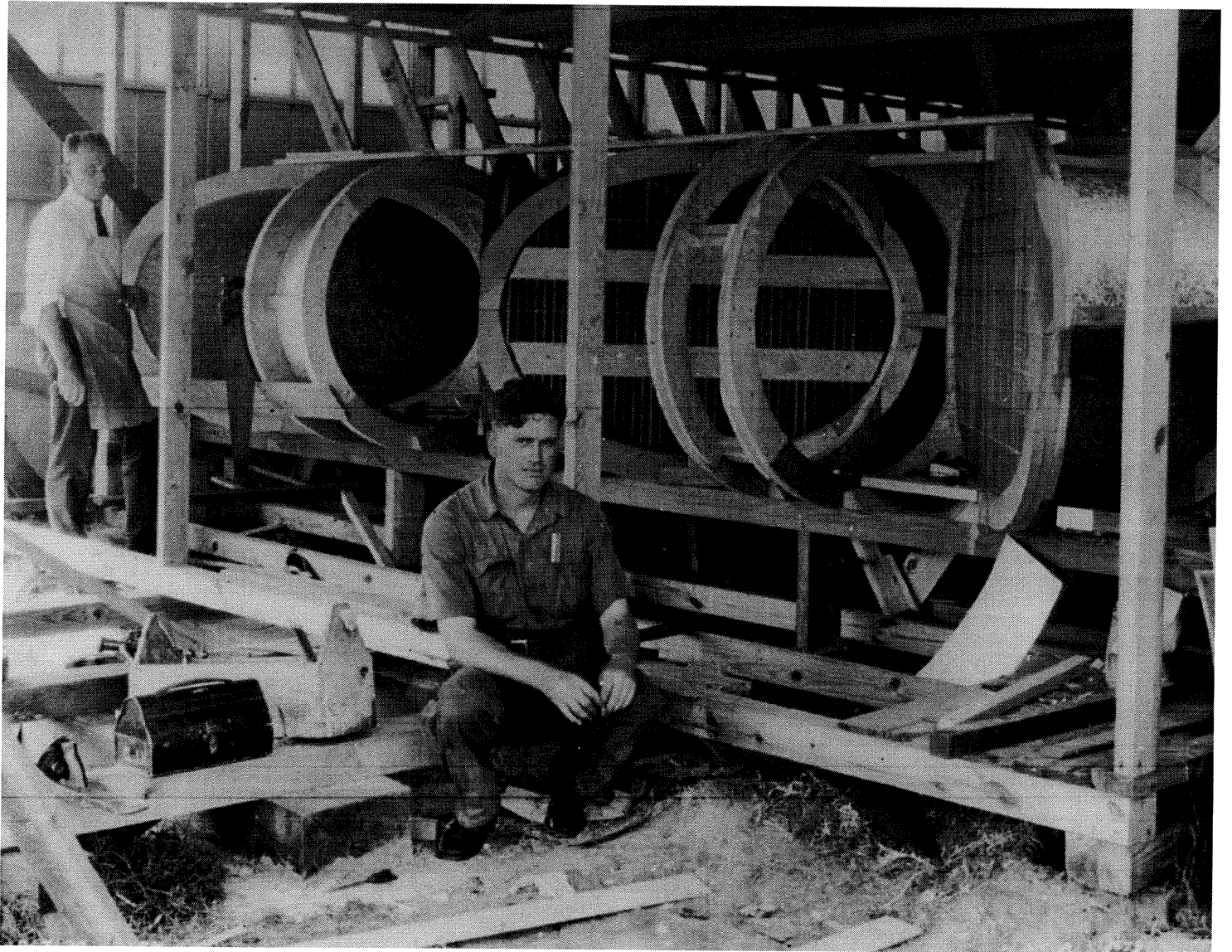
Design and construction work began in earnest. In June, George Lewis approved DeFrance's plan to build a 1/16 working model of the wind tunnel. Reports surfacing from the California Institute of Technology concerning the newly completed wind tunnel prompted the Langley group to rethink its design. "Don't yell! Our energy ratio is somewhere between 5 and 6. I know you won't believe it; we can hardly believe it ourselves," wrote an exuberant Arthur "Maj" Klein to E.P. Lesley at Stanford. Soon the word spread through the technical community.<sup>34</sup> For example, DeFrance now wanted to study the effect on energy ratio of three different factors: 1. the design of the exit cone; 2. a circular section return passage design; and 3. the significance of the tightness of the walls.<sup>35</sup>

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<sup>33</sup>"Formation of Full Scale Wind Tunnel Section," memorandum for files from Elton W. Miller, March 27, 1929, NARA-Phila, RG 255, Box 1021.

<sup>34</sup>Judith R. Goodstein, *Millikan's School: A History of The California Institute of Technology*, (New York: W.W. Norton, 1991, p. 166 quotes A.L. Klein to E.P. Lesley, January 15, 1929, CIT, Clark B. Millikan Collection, Box 14, Fldr 14.

<sup>35</sup>"Model of Full Scale Wind Tunnel," Elton W. Miller to National Advisory Committee for Aeronautics, June 26, 1929, NARA-Phila, RG 255, Box 1021.



By the fall of 1929, DeFrance had laid out three different designs for the tunnel.

The choices he spelled out were as follows:

- (a) circular exit cones and circular to rectangular transformation in the return passages;
- (b) circular to octagonal transformation within the exit cones and octagonal to rectangular transformation in the return passages;;
- (c) circular to square with the exit cones, and square to rectangular in the return passages<sup>36</sup>

DeFrance estimated the cost for options A and B at \$375,000 and \$365,000 for option C. Within a month, he had decided to eliminate the “circular, transforming to rectangular, return passages” design. A rectangular return passage would be simpler and cheaper to construct; and, it would increase the number of contractors that could bid on the job.<sup>37</sup>

DeFrance also began to investigate electric motors as well as diesel engines for the tunnel’s power supply. Once Virginia Power agreed to supply electric service, the engineers immediately rejected the use of diesel engines.<sup>38</sup> A short trip to visit the Bethlehem Steel plant at Sparrow’s Point near Baltimore and the Berliner-Joyce Aircraft Company’s wind tunnel located near Washington helped engineers resolve certain knotty design problems. At Bethlehem Steel, the chief electrical engineer squired DeFrance and Miller around all of the plant’s electrical installations. DeFrance and Miller were especially interested in the wall construction of the Berliner-Joyce tunnel (plaster on metal lath).<sup>39</sup>

For the next eighteen months, DeFrance was in the thick of construction. All of the major construction contracts were signed, the most important one being the general construction contract with the J.A. Jones Company of Charlotte, North Carolina. J.A. Jones

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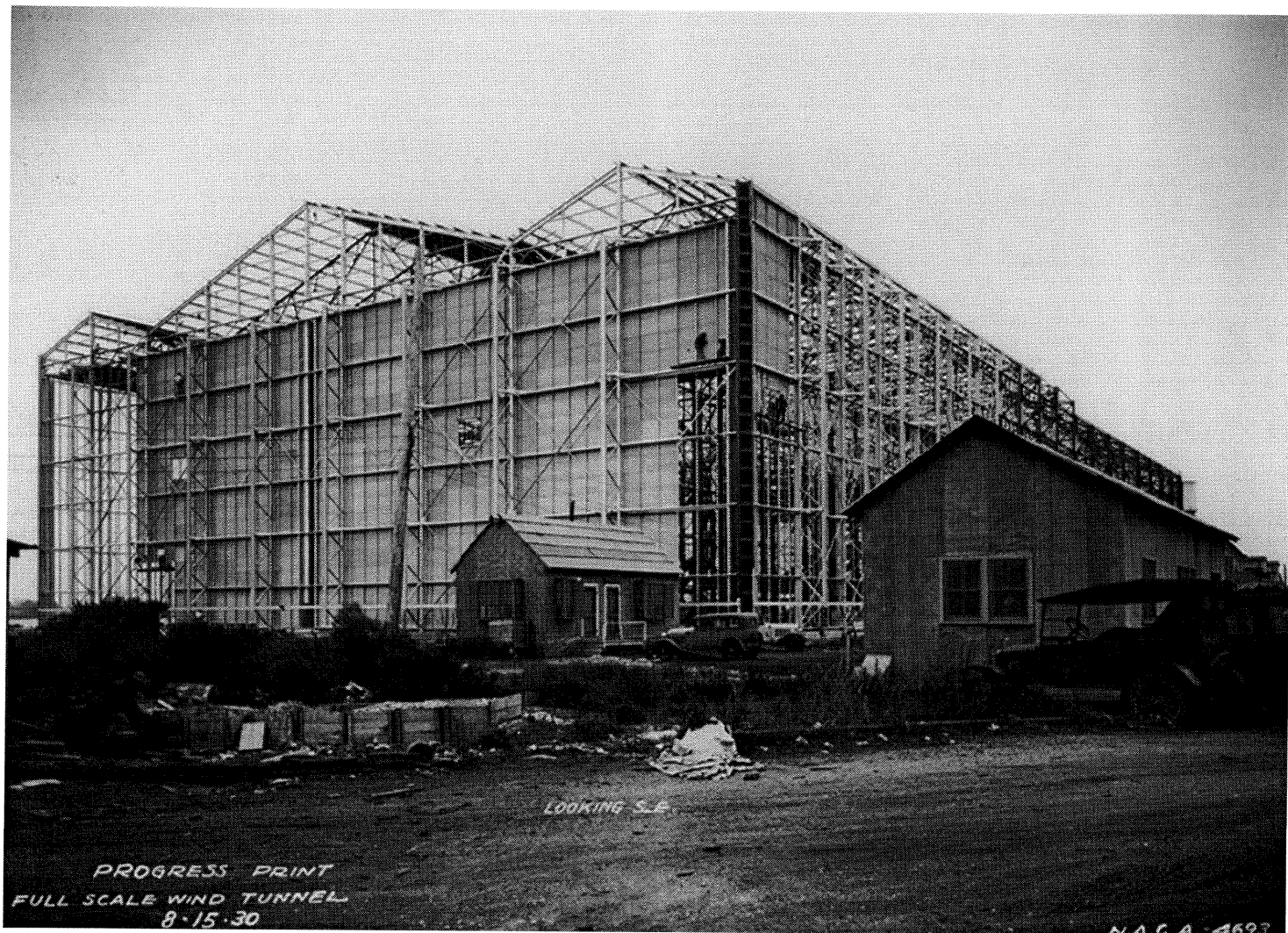
<sup>36</sup>“Design of Full Scale Wind Tunnel,” Smith J. DeFrance to Chief, Aerodynamics Division, October 24, 1929, NARA-Phila, RG 255, Box 1021.

<sup>37</sup>“Recommendation for general design of Full Scale Wind Tunnel,” Smith J. DeFrance to Mr. Miller, November 5, 1929, NARA-Phila, RG 255, Box 1021.

<sup>38</sup>“Transmission line to Full Scale Wind Tunnel,” Smith DeFrance to Engineer-in-Charge, December 10, 1929, NARA-Phila, RG 255, Box 1021.

<sup>39</sup>“Visit to Sparrows Point, Md., and Washington, D.C. on December 9, 1929,” Elton Miller to Engineer-in-Charge, December 13, 1929, NARA-Phila, RG 255, Box 1021.





LOOKING S.E.

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FULL SCALE WIND TUNNEL  
8-15-30

NACA 4693

was not the first choice of DeFrance and he arranged to send a new civil engineer just hired by the NACA to Charlotte to spy on the company and see if he could come up with a reason for disqualifying the firm. Unfortunately, Eugene Lundquist not only thought the Jones design was the best of the bunch but also he was a scrupulously honest midwesterner who blurted out the true nature of his mission within minutes of arriving at the Jones' offices.<sup>40</sup>

The construction lasted about one year and the first tests were made in the spring of 1931. As described earlier George Lewis decided that the Full Scale Tunnel (and the new Seaplane Towing Channel) would be dedicated during the Sixth Annual Inspection in May 1927. Over two hundred people were invited and the day was an exciting one. Joseph Ames commented that: "The completion of this wind tunnel opens up a new vista of important problems, the solution of which I am confident will mean much toward increasing the safety and efficiency of aircraft."<sup>41</sup>

It took four years to build a consensus among NACA engineers that the project was worthwhile; persuading Congress to steadily increase its appropriations for the NACA had been a decade long process, and it still took several months to build support for this particular new wind tunnel; finally, it took two more years to design and build the tunnel. It is ironic that for all this effort, the engineers had never actually spelled out a research program for this grandiose new wind tunnel.<sup>42</sup>

### *Research During the First Decade of Operation*

Years after the tunnel opened Abe Silverstein observed that there was no "plan." Silverstein, a junior engineer (he later became the director of NASA Lewis), hired just before the Stock Market Crash in 1929 noted:

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<sup>40</sup>Eugene E. Lundquist, oral history interviews, May 6 and June 22, 1996.

<sup>41</sup>"Proceedings of Sixth Annual Aircraft Engineering Research Conference," p. 23.

<sup>42</sup>Abe Silverstein, Oral history interview conducted by John Mauer, March 10, 1989, Glennan-Webb-Seamans Project for Research in Space History, National Air and Space Museum, Smithsonian Institution, p. 8. Used with permission.



The idea of building the tunnel apparently had been Dr. Lewis's concept, and I don't think he had anything particular in mind. He was in charge of NACA in Washington, and I don't think he felt that there was any detailed program necessarily, but he felt that this was a good idea. And it was a good idea. It was a splendid idea, the best idea that came down the pike in a long time. But the detailed program, of course, simply didn't exist.<sup>43</sup>

The way Ames had put it at the "dedication" was that it was up to the military and industry to supply a research agenda. The NACA had done its job by bringing this "most wonderful machine" into existence. The Committee had already received many suggestions, and it is clear that these engineers were fully supportive of the project. Many who spoke during the afternoon comment session of the 1931 inspection felt moved to make effusive expressions of appreciation. Jerome Hunsaker called the NACA engineers "men of vision and courage." Edward Warner echoed Hunsaker's remarks and added his own proposal for an extension of engine nacelle placement research in the new tunnel.<sup>44</sup>

Initially, the lack of a clear agenda went unnoticed because it took much longer than expected to calibrate the tunnel as well as to devise suitable test procedures. The early claims of zero turbulence proved incorrect but overall early test results were gratifying. Full-scale testing proved more time-consuming and more costly than tests in smaller facilities such as the VDT. James Hansen has described the "debate" between the engineers of the FST and VDT groups of Langley in dialectical terms.<sup>45</sup>

As engineers in these two groups fought over everything from tunnels to sports (recreation leagues at Langley organized teams by research group), each claimed better access to aerodynamic truth. So neither was prepared when Langley's brilliant physicist Theodore Theodorsen told them that they had missed the point by making tunnels and

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<sup>43</sup> Silverstein interview.

<sup>44</sup> "Proceedings of Sixth Annual Aircraft Engineering Research Conference," p. 31-32, 33-34.

<sup>45</sup> Hansen, pp. 99-105.

testing the end objective. In the future, Theodorsen believed that success would depend on knowing “why.” Engineers in both VDT and FST groups, argued Theodorsen had become experts at “how.” The point was not to perfect equipment but to use equipment to expand aeronautical engineering knowledge. Theodorsen’s was a harsh assessment, which many at Langley (and elsewhere) proved unwilling to accept.<sup>46</sup>

### *The Sublime Tunnel*

The Full Scale Tunnel did not achieve its research objective or the pioneering status that other wind tunnel facilities had. Yet, the facility’s critical importance to the history of the NACA and Langley can not be overstated. Engineers made great use of the facility and it has proven invaluable over many decades for development studies. The historic significance of the Full Scale Tunnel derives from its monstrous size and the tremendous emotional reaction that visitors experienced when seeing the tunnel for the first time. As Brooke Hindle once reminded us, technology is exhilarating. Ordinary people do not experience technology as intellectual abstractions. An airplane in flight is a “miracle” to be wondered at, not an assemblage of scientific puzzles like boundary layer theory.

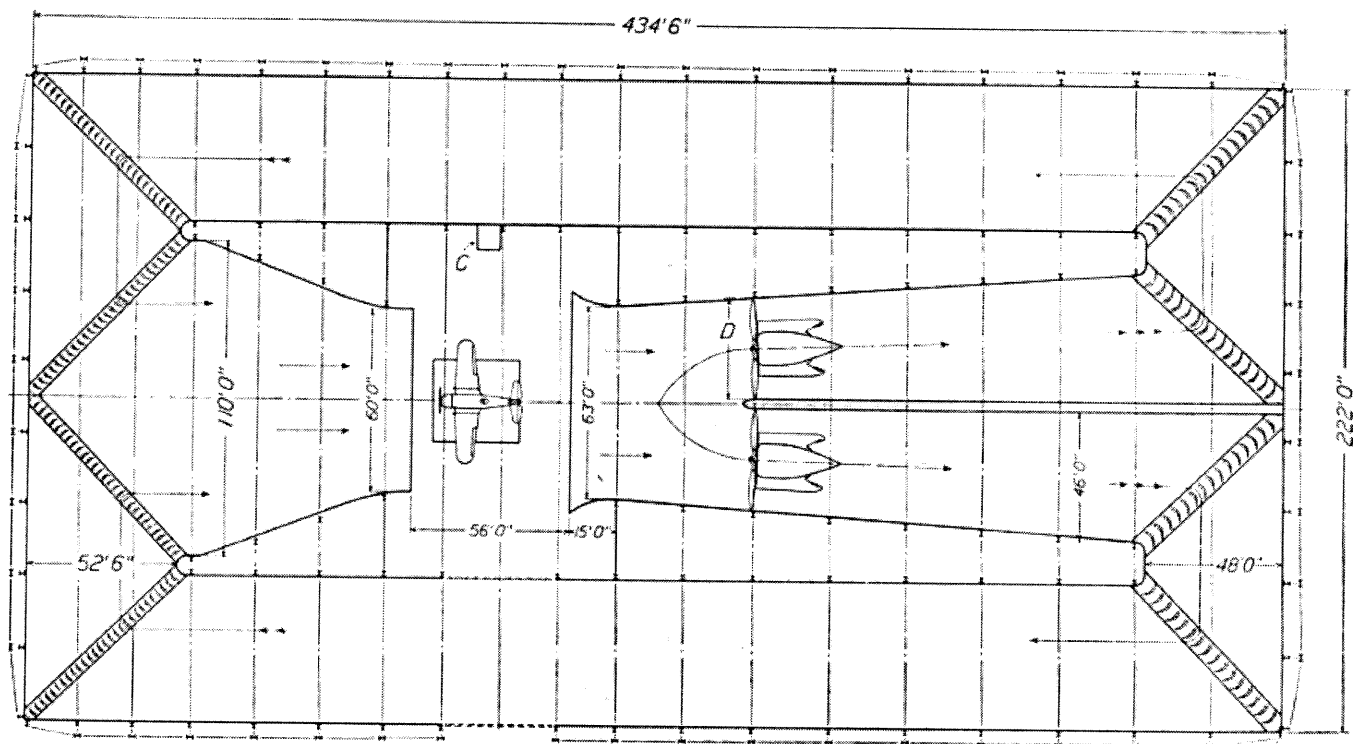
Throughout the nation’s history, Americans have experienced (both individually and collectively) emotional responses to technological achievement that have fundamentally shaped their perceptions of the world. David Nye made the first extended analysis of this relationship with technology which has been called by various historians the “technological sublime.” According to Nye, the sublime is an experience which evokes awe and wonder, coupled with some aspect of terror, “emotional configurations that both emerge from and help to validate new social and technological conditions.”<sup>47</sup> Nye’s main interest in the book, however, is in “phenomena that attracted maximum national attention....”<sup>48</sup> While the Full Scale Tunnel did attract an impressive amount of attention, it is clearly in a different

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<sup>46</sup>Hansen, pp. 105-108. Others besides Theodorsen level criticisms at the NACA. Most notable was the scathing attack made by Frank Tichenor, editor of *Aero Digest*, in 1930. Alex Roland has summarized this episode in *Model Research*, pp. 130-138.

<sup>47</sup>Nye, p. xvii.

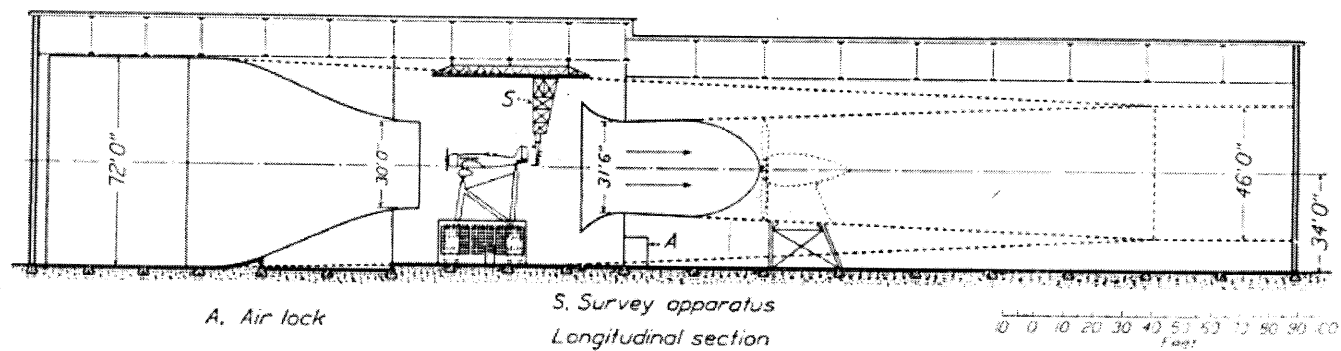
<sup>48</sup>Nye, p. xvi.



C. Control

Plan

D. 35'6 1/2"



A. Air lock

S. Survey apparatus  
Longitudinal section

10 0 10 20 30 40 50 60 70 80 90 100  
Feet

FIGURE 1.—Plan and elevation of the tunnel.

category from the Empire State Building or Apollo rocket launches. Nonetheless, Nye's analysis offers a powerful interpretative framework with which to situate this utilitarian research instrument within the larger culture.

First, both the NACA officials and outsiders recognized immediately the fact that the tunnel's sheer volume was impressive. Almost every reference in official reports mention that the FST is the "world's largest" wind tunnel. Stories about the "Behemoth of Wind-Tunnels"<sup>49</sup> not only appeared in all the major newspapers, science and engineering publications but also in *Literary Digest*.<sup>50</sup> Photographers took advantage of the toy-like appearance of the aircraft undergoing tests in the tunnel. Most pictures were arranged to show a solitary figure dwarfed by the large entrance or exit cones. These arrangements hearken back to the oldest variation of American sublime experiences which pit puny man against majestic nature.

Sheer size was not enough, however. Other structures were larger than the FST, including the lighter-than-air hanger just across the airfield. What made the FST special was that it was a giant scientific instrument and not just a big building. Again, though a critical aspect of sublime experiences is the sense of danger. In the case of the FST this sensation came from the knowledge that the engineers could manufacture maelstroms at will. The tunnel's airstream was often compared with a hurricane...indoors.

The three major movie news reel companies wanted to film pieces on the FST shortly after its "dedication." The one surviving "script" is extremely interesting and reveals what sorts of images that film makers thought would impress a lay audience. It notes that "very effective and spectacular scenes can be made from inside the mouth of the tunnel. Perhaps the air force can be brought to within 40 miles per hour...." The opening scene featured the archetypal aviator with white scarf being blown away by the rush of air. While most of the piece would be devoted explaining technology, the scriptwriter was

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<sup>49</sup>"Behemoth of Wind-Tunnels," *Popular Aviation* 19 (September 1936): 31-32, 60.

<sup>50</sup>Alexander Klemin, "Testing Full-Sized Air-Planes in Wind-Tunnels," *Literary Digest* 119 (April 27, 1935): 16.

adamant that “light relief” was vital. In this example, the script called for “a scene of lady visitors being escorted through the return passage and wind vanes. Show the propellers being turned on with sufficient force to causing a little difficulty for the ladies to make headway.”<sup>51</sup>

Stories involving women were perceived as especially effective means for communicating the idea of danger. There is a famous, perhaps apocryphal, story related to Amelia Earhart’s first visit to Langley shortly after her first transatlantic flight. Supposedly her raccoon fur coat got sucked into one of the wind tunnels during the tour of the laboratory, although there is no evidence to document this tale. The point of the story (which exploits gender stereotypes as does the movie script) is to remind viewers of how the wind was “tamed” (mostly) by man for the service of science. In his chapter on factories, Nye describes the overwhelming impression the visitor gets is the “sublime demonstration of man’s ingeniousness and superior intellect.”<sup>52</sup>

Other expressions of the sublime are drawn more subtly. Exterior photographs of the FST show that the tunnel is set right on the edge of the Back River. Electric motors eliminated the smoke and noise which would have been by-products of using old submarine diesel engines to power the tunnel. The picture is serene (unless flooding conditions happen to be present) and suggests the pastoral era of mills and water power—the machine in the garden. The paradox of this situation is that the wind tunnel was a symbol of modernity and its interiors remind observers of the twentieth century values of control, system and order.

Unlike real factories, the public could not visit this “Temple of the Winds”<sup>53</sup> but for aeronautical engineers the Full Scale Tunnel was Stop No. 1 on the annual “pilgrimage” to Langley.<sup>54</sup> The religious vocabulary is yet another indicator of the

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<sup>51</sup>“Proposed outline of moving pictures to be taken at full-scale wind tunnel,” Charles Charlton, Paramount Publix Corporation, February 1932. NARA-Phila, RG 255, Box 1021.

<sup>52</sup>Nye, p. 115.

<sup>53</sup>“Temple of the Winds,” *Flight* 27 (April 11, 1935): 380.

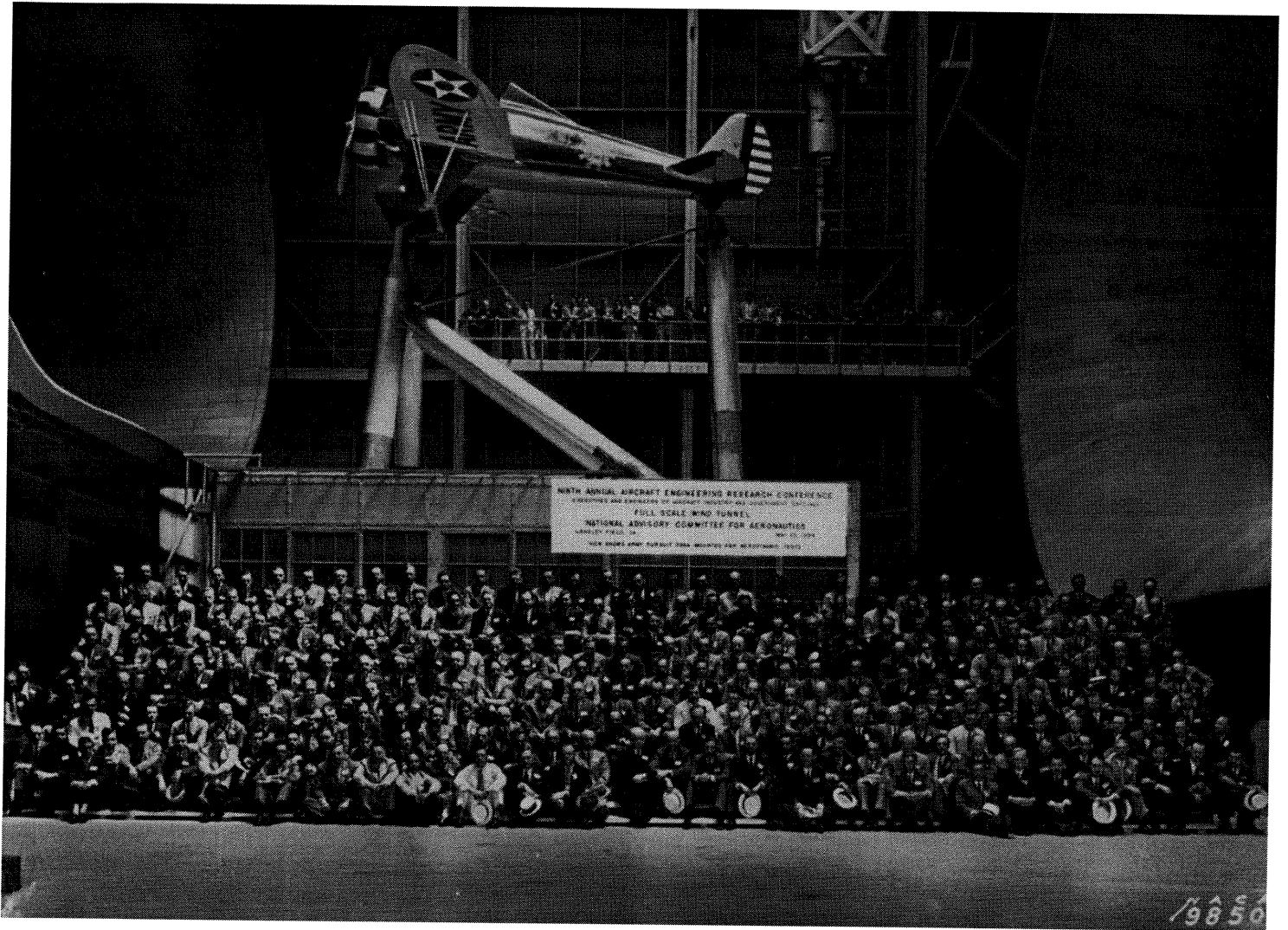
<sup>54</sup>“Pilgrimage to Langley: A Year’s Research Progress,” *Aviation* 31 (July 1932): 301.

sublime according to Nye, as religious imagery and expression were much more central in the minds of Americans in this period. This is not to suggest that the writers always employed such terms literally. Yet even when the terms “pilgrimage” or “temple” are used in a secular sense, it should be noted that the annual NACA inspection at Langley was intended to foster some of the same aspects of communal relations as the original pilgrimages to Jerusalem and elsewhere supplied to faithful travelers.

In the years before World War Two, the single most important contribution of the NACA was its role as catalyst in the maturation of aeronautical engineering as a discipline. Peter Jakab has written on the importance of the Army and the engineering laboratory at McCook Field during aviation’s adolescence but gradually, and especially by the 1930s, the NACA and Langley assumed the role as unifying agent for an aeronautical engineering diaspora.

To the long list of ways the NACA has contributed to aeronautical engineering, I want to suggest the importance of image and example. American aeronautical engineering is a hybrid practice combining the theoretical and the practical. In addition to doing research, it should be recognized that outsiders learned as much about “how” the Langley engineers undertook a project as they did from the research results. The famous rivalry between Eastman Jacobs and Theodore Theodorsen was not something individuals like George Lewis bragged about but this was precisely the tension within the larger technical community. Reconciling powerful forces turned out to an ongoing struggle that was never fully complete. Even more important the tension and the competition had a positive side as well.

Peter Galison has provided a provocative theoretical description of research activity among supposedly incommensurate research communities (ones operating within different paradigms). In particular he describes the boundary areas between different scientific subcultures as “trading zones” in which participants create a ‘pidgin’ language to translate and mediate the work and practices of the various disciplines. This hybrid language made it



possible for members of different groups to exploit the insights of outsiders.<sup>55</sup> Instead of a 'pidgin' language, I want to suggest that the Full Scale Tunnel and the sublime experiences that it evoked fulfilled the similar mediating function. Just as the concept of visual thinking is critical to historians trying to document the thought and work of engineers and inventors, so too are experiences of the sublime. This aspect (the sublime) of the FST was discovered even before engineers realized that full-scale tunnel technology would never achieve the kind of impact that other facilities had.

The vast scale of the FST conveyed the importance of long term investment in research equipment, of institutional permanence and of aviation's prominent place in the life of the nation. But gigantic technology (whether telescope, skyscraper, or bridge) resonated deeply with American values. The first three decades of the twentieth century were a remarkable period in American history. Massive technological systems were "installed" across the nation bring new means of transport, communications and human comfort. Giant industrial organizations employed systems of mass distribution and production to supply unprecedented material goods to Americans. In the U.S. Chamber of Commerce's retrospective on the quarter century, 1912-1937, entitled "Those Tremendous Years," the first observation: "There is, for one, the new recognition by business of a necessary comradeship with research is striking."<sup>56</sup> The Full-Scale Tunnel was one manifestation of this trend.

The public, *if* they knew what the initials N.A.C.A. stood for—and most did not—saw the organization's mission to make airplanes fly faster, further, higher and safer. In the Full Scale Tunnel, though the price tag was steep, they could easily apprehend the fact that the engineers at Langley were upholding that mandate. To the aeronautical engineering

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<sup>55</sup>Peter Galison, "Computer Simulations and the Trading Zone," in *The Disunity of Science: Boundaries, Contexts, and Power* ed. by Peter Galison and David J. Stump (Stanford University Press, 1996), pp. 118-157.

<sup>56</sup>"These Tremendous Years: Flashes from the History of a Quarter Century of Business Achievement," reprinted from *Nation's Business* (May 1937) by the U.S. Chamber of Commerce, p. 63.



community, the sublime experience of the FST communicated an additional and critical message. The “message” was not a didactic one but rather an invitation to the scores of engineers who were largely untrained in higher mathematics and deeply skeptical of “theory” that these activities were vital to the discipline’s future development. C.N. Montieth was the chief engineer for Boeing and before that one of the top engineers at McCook Field. He authored one of the basic texts in aircraft design and he had an abiding passion for airplanes. Montieth was a pragmatist who was skeptical of theoreticians. These facts make the following excerpt from his trip report covering his participation in the 1930 Annual Inspection all the more compelling:

...the group visited the big wind tunnel, the most impressive piece of apparatus in the laboratory. The pictures of this give no appreciation of its real size, and *one cannot help but feel that the results obtained here are really dependable full scale data*. They are now constructing a tunnel which will have a throat 30' x 60' ....<sup>57</sup> (emphasis mine)

Montieth was not a big fan of the NACA but his words reveal how the visual and emotional experience—the sublime experience of technology—could change even deeply held convictions.

During World War Two, the Full Scale Tunnel found a unique mission serving the military and industry through an elaborate drag clean-up program. That is the work that most refer to today when asked to explain the wind tunnel’s historic significance. This paper has attempted to suggest it is the slack jaw, wide eyes and head turned heavenward that are better clues to understanding the FST’s role in shaping the American aeronautical engineering community and the contributions made by the federal government to aeronautics in the United States.

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<sup>57</sup>“Continued Report on Trip East,” C.N. Montieth to G.W. Carr, June 6, 1930, Boeing Historical Archives.